DSL TRANSMISSION SYSTEM WITH FAR-END CROSSTALK CANCELLATION

Background Of The Invention

1. Field of the Invention

The present invention relates to digital subscriber line transmission systems, which allow, in particular, high speed communication on twisted pair telephone lines based on discrete multitone transmission (DMT). The invention relates more specifically to a far-end crosstalk (FEXT) canceller for canceling the crosstalk signal induced by modems located at the far-end of such a transmission system.

2. Discussion of the Related Art

Figure 1 schematically shows a modem in a conventional DSL transmission system using discrete multitone. The modem includes a transmitter TX and a receiver RX. A serial stream of data X is provided to a mapper circuit 11 mapping each data into a symbol of a constellation, for example of a QAM (Quadrature Amplitude Modulation) constellation. The mapped values are then transformed into a set S of N components by a serial to parallel converter 12, each component of the set being considered as a frequency domain coefficient. This set of frequency domain coefficients, hereafter also called DMT symbol, is provided to an inverse fast Fourier transform (IFFT) circuit 13 which generates a time domain block of samples and is followed by a parallel/ serial converter (P/S). This time domain block is therefore the sum of N sinusoidal subcarriers of different frequencies, the amplitude thereof being determined by the corresponding frequency domain coefficient received by the IFFT circuit.

Each time domain block is cyclically prefixed (cp) and suffixed (cs) in a block 19 to eliminate or at least attenuate the Inter Symbol Interference (ISI) and the Inter Carrier Interference (ICI) caused by the channel, and is transmitted onto a telephone line 10 through a hybrid line interface 18. The line interface 18 also receives incoming time domain blocks from another modem connected to line 10.

At the receiving side, the incoming time domain blocks from line 10 are provided to a fast Fourier transform (FFT) circuit 14 through a block 19' that deletes the prefix and suffix and a serial/parallel converter (S/P) which calculates the N frequency domain coefficients for each block. The N frequency domain coefficients are then provided to an

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equalizer 15 which compensates for the attenuation and phase shift incurred by each frequency component. The equalized values are then serialized by a parallel to serial converter 16 into a stream of N complex numbers R(fj) and then processed by a demapper 17 attributing to each R(fj) the symbol $\hat{S}$c of the constellation which comes closest thereto. The demapper 17 further outputs the digital word $\hat{X}$c associated with the selected constellation point $\hat{S}$c.

Figure 2 schematically shows a DSL transmission system including a central office 20 communicating with a plurality of end-users over telephone lines 25, 26. Modems 21, 22, 21', 22' have the structure represented in figure 1. The end of a telephone line connected to a modem of the central office 20 is called the line termination (LT) side while the end connected to a modem of an end-user is called the network termination (NT) side.

Ideally, such a DSL transmission system allows the whole frequency band to be used for simultaneous full-duplex transmissions. However, in practice, different sources of noise disturb the transmissions and impede proper reception of data.

For a given modem, three different sources of noise can be distinguished as illustrated in figure 2:

- the self-echo, i.e. for a given modem, the parasitic signal from the transmitter TX leaking to the receiver RX through the hybrid interface;

- the near-end crosstalk (NEXT) arising from signals in adjacent telephone lines 25, 26 with opposite transmission directions. More specifically, in the present example, the NEXT generated at the modem 21 is the parasitic signal received by this modem from the modem 22. In this instance the NEXT is called LT-NEXT because the modem 21 is located on the LT side. Reciprocally, the NEXT generated at modem 21' by the modem 22' is called NT-NEXT;

- the far-end crosstalk (FEXT) arises from signals traveling along the same transmission direction in adjacent telephone lines. More precisely, in the illustrated example, the FEXT generated at the modem 21 is the parasitic signal received by this modem from the modem 22' located on the opposite side, due to the coupling between the telephone lines 25 and 26 sharing a common binder. In this instance the FEXT is called LT-FEXT because the modem 21 is located on the LT side. Reciprocally, the FEXT generated at modem 21' by the modem 22 is called NT-FEXT.

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Echo-cancellers for canceling self-echoes are known e.g. from U.S. patent application number 09/410,636, filed October 1, 1999 and entitled DSL TRANSMISSION SYSTEM WITH ECHO-CANCELLATION, which is incorporated herein by reference.

There is also known from U.S. Patent Number 5887032, which is incorporated herein by reference, a canceller for canceling out the NEXT interference in an ADSL transmission system on the LT side. This canceller operates in the frequency domain and assumes, for a given subcarrier or tone, that the NEXT interference is proportional to the symbol value emitted by the modem transmitting on the interfering channel. The latter value is scaled by a given coefficient and subtracted from the symbol received by the modem suffering from the NEXT interference.

Both self-echo cancellation and LT-NEXT cancellation are possible because the signal transmitted by the same modem (in the case of the self-echo) or by a neighboring modem of the central office (in the case of LT-NEXT interference) is directly available.

FEXT cancellation is however intrinsically more complex than NEXT or self-echo cancellation because the modem transmitting over the interfering channel is now located on the far-end side and the actual values of the interfering symbols are therefore not known.

Summary Of The Invention

An object of the present invention is to design a canceller circuit for a DMT based DSL transmission system capable of significantly removing the FEXT interference and having a simple structure.

Another object of the present invention is to design an efficient FEXT canceling method in a DMT based DSL transmission system.

These and other objects are achieved by a far-end crosstalk canceling circuit for a digital subscriber line transmission system, said transmission system comprising a plurality of line termination modems receiving discrete multitone signals from corresponding network termination modems over a plurality of transmission channels, each modem comprising time/frequency transforming means for transforming said discrete multitone signals into a discrete multitone symbol of frequency components and demapping means outputting for each frequency component the symbol of the constellation nearest thereto and the corresponding demodulated data; estimation means, in at least one line termination modem, for estimating the constellation symbols actually sent by the network termination

modems, from the frequency components of the discrete multitone symbols received by all modems; calculation means for calculating a linear combination of said estimated modulated data, for subtracting said linear combination from the frequency components of said at least one line termination modem and for applying a resulting difference to the demapping means of said at least one termination modem; error calculation means for calculating the error distance between the constellation symbol from said at least one line termination modem and said difference; and updating means for updating the coefficients of said linear combination as a function of said error distance.

The invention also provides a far-end crosstalk canceling method for a digital subscriber line transmission system, said transmission system comprising a plurality of line termination modems receiving discrete multitone signals from corresponding network termination modems over a plurality of transmission channels, each line termination modem comprising frequency transforming means for transforming said discrete multitone signals into a discrete multitone symbol of frequency components, and demapping means outputting for each frequency component the symbol of the constellation nearest thereto and the corresponding demodulated data, the method comprising the steps of: estimating, for at least one line termination modem, the constellation symbols actually sent by all the modems from the frequency components of the discrete multitone symbols received by said modems; calculating a linear combination of said estimated symbols, subtracting said linear combination from the frequency components of a discrete multitone symbol and applying the resulting difference to the demapping means of said at least one modem, to obtain a constellation symbol; calculating the error distance between said constellation symbol and said difference; and updating the coefficients of said linear combination as a function of said error distance.

The foregoing and other objects, features, aspects and advantages of the invention will become apparent from the following detailed description of embodiments, given by way of illustration and not of limitation with reference to the accompanying drawings.

Brief Description Of The Drawings

Figure 1, previously described, schematically shows the structure of a modem suitable for use in a DSL transmission system;

Figure 2, previously described, schematically shows the different types of noise

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occurring in a DSL transmission system;

Figure 3 shows a first and a second embodiment of a FEXT canceller according to the invention;

Figure 4 shows a third embodiment of a FEXT canceller according to the invention;

Figure 5 shows a fourth embodiment of a FEXT canceller according to the invention; and

Figure 6 schematically shows the overall structure of a DSL transmission system comprising a FEXT canceller according to the third or the fourth embodiment of the invention.

Detailed Description

The invention is based on the idea that the actual value of a symbol causing FEXT interference at the LT side can be obtained from the modem receiving this symbol. The modem receiving the FEXT interfering symbol and the modem receiving the FEXT corrupted symbol being both located at the central office, a connection between the two modems can be realized.

Figure 3 shows a first embodiment of the invention and more specifically a part of the receiver TX of a modem p on the LT side, receiving a FEXT corrupted signal. In this embodiment the blocks 38 and 39 represented with dotted lines do not exist.

Each modem i on the LT side is connected to a modem c(i) on the NT side through a transmission channel. The blocks 35, 36, 37 correspond to the blocks 15, 16, 17 of the receiver RX illustrated in figure 1.

This first embodiment aims at canceling the FEXT interference caused by the signals transmitted by n-1 modems c(i), i=1 to n, $i \neq p$.

For clarity purpose, suppose first that a symbol carried by the subcarrier or tone fj is FEXT corrupted by symbols at the same frequency only. If, as illustrated on figure 2, H(fj) = $(H_{kl}(fj))$ the transfer matrix of the n transmission channels from the NT to the LT side, with k,l = 1...n, fj being the frequency index with j = 1...n, we can write in the frequency domain for the frequency fj:

$$R(fj) = H(fj)*S(fj),$$

where R(fj) = Rk(fj), k = 1...n, is the vector of the received frequency components and S(fj) = Sk(fj), k = 1...n, is the vector of the transmitted DMT symbols from the n modems, for the

frequency fj.

The FEXT interference for a given frequency fj and for a modem p can therefore be written:

$$\text{FEXT(fj)} = \sum_{l=1}^{n} Hlp(fj)Sl(fj)\,,\ l \neq p$$

According to the first embodiment of the invention, the complex values Sl(fj), l=1...n, l≠p are approximated by the symbols $\hat{S}$ l(fj), i.e. by the symbols of the constellation coming the closest to the respective received frequency components Rl(fj), l=1...n, l≠p, respectively output by the demappers 37. This implies that the processing in the modem p is one-symbol delayed with respect to the other modems.

The complex symbols $\hat{S}$ l(fj) from the other modems, l=1...n, l≠p, are then linearly combined in block 34 and subtracted by a subtractor 31 from the received frequency component Rp(fj) to produce a FEXT-removed complex value Tp(fj). The demapper 37 of modem p outputs a demapped word $\hat{X}$ p(fj) and the corresponding constellation point $\hat{S}$ p(fj). The complex value $\hat{S}$ p(fj) is subtracted from the complex value Tp(fj) to produce an error value. This error value is squared in a circuit 32 and processed in a block 33 to update the coefficients of the linear combination, for example according to the known steepest gradient algorithm. The updated values stored in block 33 will be used for FEXT canceling the next frequency component Rp(fj), i.e. the frequency component Rp(fj) of the next incoming block. After a few iterations, the linear combination coefficients converge towards the values Hlp(fj) of the transfer matrix.

We have considered above FEXT cancellation at a single tone fj. It is clear however that the processing should be repeated for all the tones j=1 to N, the frequency coefficients Rp(fj) being sequentially output by the parallel to serial converter 36. The linear combination coefficients for each frequency fj are stored in the memory of block 33. After a few iterations the memory contains the values Hlp(fj), l=1...n and l≠p, j=1...N.

We have assumed above that the FEXT at the different frequencies could be independently canceled. In a conventional DMT transmission system this can only be regarded as an approximation since the limited duration of the time domain blocks causes a spreading of the frequency components. Generally, the FEXT at a frequency fj depends also upon frequency components transmitted at neighboring frequencies. This problem can be

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tackled in two different ways.

Firstly, the crosstalk canceller of figure 1 can be adapted so as to take into account intra-frequency crosstalk coefficients Hlp(fi,fj), the modification being straightforward: the linear combination coefficients are now function of a couple of frequencies fi, fj. The processing in modem p has also to be delayed for a full time block since the knowledge of the $\hat{S}$ l(fj) at all the frequencies is necessary before starting the FEXT cancellation.

Secondly, if the modems are synchronous Zipper modems as described in the international application WO97/06619, which is incorporated herein by reference, the assumption made above is fully valid, i.e. the FEXT at a frequency fj is independent from the frequency components transmitted at the frequencies fi, i≠j. Indeed, in such modems, the cyclic extension added to each time domain block before transmission eliminates any inter-frequency crosstalk.

Figure 4 shows a second embodiment of the invention. In this embodiment, the FEXT second interference is canceled in a centralized manner by a crosstalk canceller 40 operating now for all the LT modems or at least for all the LT modems cross-linked by the same FEXT. The crosstalk canceller 40 receives the sets of frequency components Ri, i=1 to n (Ri=Ri(fj), j=1 to N) from FFT circuits 44 and uses Ri to approximate Si(fj). At time t, the vector R constituted by the Ri's is multiplied by the matrix H^{-1}_{t-1} which is an estimate of the inverse of the transfer matrix at time t-1. The resulting vector is split up in n sets $(H^{-1}_{t-1} *R)_i$, each having N frequency components. Each set is parallel to serial converted by converters 46 and the frequency components $(H^{-1}_{t-1} *R)_i$ (fj) are then demapped by demappers 47. The demappers 47 output the nearest constellation symbols $\hat{S}$ i(fj) and the digital words $\hat{X}$ i(fj) associated therewith. For each line i, the N consecutive symbols $\hat{S}$ i(fj) belonging to the same time domain symbol are converted back by serial to parallel converters 48 and fed back to the crosstalk canceller circuit 40. The resulting vector $\hat{S}_t$ of N*n components is built and the vector H^{-1}_{t-1} *R is subtracted therefrom, giving an error vector of norm e_t. The coefficients of the matrix H^{-1}_{t-1} are then updated, for example according to the steepest gradient algorithm, to produce at time t+1 an updated matrix H^{-1}_t. The previous processing steps are iterated.

In contrast with the first and second embodiments, it should be emphasized that equalization is directly provided by the crosstalk canceller itself since it is taken into

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account by the diagonal coefficients of the matrix H^{-1}_t. In this embodiment the equalization coefficients and the crosstalk coefficients are co-estimated instead of being sequentially estimated. This leads to a more accurate evaluation of both groups of coefficients.

Figure 5 shows a fourth embodiment of the invention.

No assumption as to inter-frequency FEXT has been made with respect to the third embodiment. However, as discussed above, if the modems are of the synchronous Zipper type, the inter-frequency FEXT is negligible and the matrix H^{-1}_t has the simple form of a block matrix exhibiting blocks $H^{-1}_t(fj)$, j=1 to N along its diagonal. In such an instance, FEXT cancellation can be performed sequentially for each frequency in a more simple way, as illustrated by figure 5. In contrast with figure 4, parallel to serial converters 56 sequentially provide the frequency components Ri(fj) to the crosstalk canceller 50. The product of the vector R(fj) constituted by the Ri(fj)'s is multiplied by the matrix $H^{-1}_{t-1}(fj)$ which is an estimate of the inverse of the transfer matrix at time t-1 and frequency fj. The N components (complex scalar values) of the resulting vector are demapped by demappers 57 and the respective closest constellation symbols $\hat{S}$ i(fj), i=1 to N are fed back to the FEXT canceller. The error calculation and the updating of the coefficients are a simple transposition of those set out in the description of the third embodiment.

Figure 6 shows the overall structure of a DSL transmission system with a FEXT canceller 60 according to the third or the fourth embodiment connected to n LT modems M1... Mn. Each modem is connected to a bi-directional transmission line 61, an input Din and an output Dout for inputting the digital words X(i) to be transmitted and outputting the received words $\hat{X}$ i(fj). In addition, each modem has an input 63 for inputting the values $(H^{-1}*R)_i$ and an output 62 for outputting the nearest constellation symbols $\hat{S}$ i(fj).

Although the embodiments have been described with an adaptation of the linear combination coefficients / matrix coefficients for each time domain block received, it should be understood that this adaptation can be made at a much lower rate, depending upon the characteristics of the transmission channels.

Having thus described at least one illustrative embodiment of the invention, various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description is by way of example only

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and is not intended as limiting. The invention is limited only as defined in the following claims and the equivalents thereto.

What is claimed is:

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